A Quantitative Analysis of the Benefits of Prototyping Fixed-Wing Aircraft

Walter B. Harvey, Major, USAF and Charles M. Ryan, Major, USAF

AFIT/GSE/ENV/12-J

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GSE/ENV/12-J

A Quantitative Analysis of the Benefits of Prototyping Fixed-Wing Aircraft

Presented to the Faculty

Department of Systems and Engineering Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Systems Engineering

Walter B. Harvey, Major, USAF and Charles M. Ryan, Major, USAF

June 2012

AFIT/GSE/ENV/12-J

A Quantitative Analysis of the Benefits of Prototyping Fixed-Wing Aircraft

Walter B. Harvey, Major, USAF and Charles M. Ryan, Major, USAF

Approved:

Dr. John M. Colombi (Chairman)	Date
Dr. David R. Jacques (Member)	Date
Dr. J. Dan Ritschel (Member)	Date

Abstract

Prototyping received renewed emphasis in the Weapon Systems Acquisition Reform Act (WSARA) of 2009 and the revision to DoDI 5000.02 that preceded it. One of the intentions of WSARA is to reduce cost growth among acquisition programs. The purpose of this research was to determine if cost growth is reduced for fixed-wing aircraft acquisition programs that used early prototyping (prior to MS B). The research also sought to identify trends between cost growth and schedule or prototyping cost. The research showed no discernible trends. While the research did not reveal a statistically significant reduction in normalized average total acquisition program cost growth, it does offer insight into the need to further clarify acquisition policy guidance.

Table of Contents

Page

Abstract iii

Table of Contents iv

List of Figures vi

List of Tables viii

I. Introduction 1

General Issue 2
Research Focus 4
Research Hypothesis and Investigative Questions 5
Methodology 5
Assumptions/Limitations 6

II. Literature Review 7

Cost Growth 7
Prototyping 12
Summary 18

III. Methodology 20

IV. Analysis and Results 25

Overview 25
Results 25
Initial Findings 25
Expanded Results 28
Relationships Between CGF and Other Program Characteristics 33
Summary 36

V. Conclusions and Recommendations 37

Conclusions of Research 37
Significance of Research 44
Recommendations for Action 44
Recommendations for Future Research 45
Summary 45

Appendix A - Acronyms 47

Appendix B – Prototyped Programs Included in Study..48

Appendix C – Non-Prototyped Programs Included in Study..49

Bibliography 50

List of Figures

Page

Figure 1: Distribution of total cost growth from Milestone II (adjusted for quantity changes and inflation).. 3

Figure 2: Quantity normalization is accomplished by removing the difference between the cost estimate at the DE quantity and the CE quantity on the total cost curve (recurring plus non-recurring cost) for the current estimate..................................... 22

Figure 3: Distribution of Total Cost Growth from MS II Adjusted for Quantity Changes 26

Figure 4: Distribution of RDT&E CGFs of prototyped programs, non-UAV prototyped programs, non-prototyped programs and non-prototyped programs that are not modifications or derivatives. 29

Figure 5: Distribution of procurement CGFs of prototyped programs, non-UAV prototyped programs, non-prototyped programs and non-prototyped programs that are not modifications or derivatives. 31

Figure 6: Distribution of total program CGFs of prototyped programs, non-UAV prototyped programs, non-prototyped programs and non-prototyped programs that are not modifications or derivatives. 31

Figure 7: Relationship of a program's SGF to its CGF 33

Figure 8: Relationship of a program's length of schedule to IOC to its CGF 34

Figure 9: CGF related to the proportion of RDT&E funds dedicated to early prototyping 35

Figure 10: CGF related to the proportion of total program cost dedicated to early prototyping.. 35

List of Tables

Page

Table 1: CGF Summary Statistics by Funding Categories for MS II 25

Table 2: CGF Summary Statistics with F-16C/D Removed 27

Table 3: CGF Summary Statistics with F-16C/D & UAV Programs Removed 27

Table 4: CGF Summary for Non-Prototyped Fixed Wing Aircraft Programs................. 28

Table 5: CGF Summary of Non-Modification/Derivative Programs for Non-UAV Fixed-Wing Aircraft Programs that Used Early Prototyping and Non-Prototyped Programs 30

Table 6: CGF Summary for Early Prototyped Fighter/Attack Aircraft Programs........... 32

Table 7: CGF Summary for Non-Prototyped Fighter/Attack Aircraft Programs 32

Table 8: Prototype Programs Included in this Study 48

Table 9: Fixed-Wing Aircraft Non-Prototyped Programs Included in the Study 49

A Quantitative Analysis of the Benefits of Prototyping Fixed-Wing Aircraft

I. Introduction

The DoD has a long history of cost growth associated with its Major Defense Acquisition Programs (MDAP). The control of cost growth in weapon systems first gained the interest of our nation's leadership during the Vietnam Conflict, but with today's national budget and debt crisis, cost growth in DoD programs has never been more important. Even then chairman of the Joint Chiefs, Adm. Mike Mullen, has stated on numerous occasions that the single biggest threat to national security is the national debt [1] [2]. Over the years several acquisition reform policies have been put into effect to control cost growth, all with varying results [3] [4] [5]. Recently, in an effort to combat climbing cost growth, Congress passed the Weapon Systems Acquisition Reform Act (WSARA) of 2009. Just prior to its release a study was done by the Government Accountability Office (GAO) that reported MDAPs had grown in cost by an estimated $296 billion [6].

It is essential to institute solid and sound policy that can be clearly followed by cost estimators, program managers, and decision makers alike to deter cost growth. WSARA attempts to do just that. This research effort analyzes the wisdom of WSARA's attempt to focus on early systems engineering principles in the acquisition process, specifically its renewed emphasis on competitive prototyping prior to Milestone B approval.

General Issue

There is no doubt that the U.S. Department of Defense, along with the individual services, has "historically underestimated the costs of new weapon programs [7]." By underestimating these programs over the years, OSD and the military services have underfunded the costs of these new weapon systems, leading to budgets that cannot be met.

A study conducted by RAND on historical cost growth of weapon systems acquisition in 2006 indicates that a completed program will show an average cost growth of 44%measured from Milestone (MS) II. This study defined a completed program, as a program that was either finished or nearly finished (greater than 90%of production complete) [8]. Figure 1 below shows the cost growth factor for programs investigated by RAND (Arena, et al.). The data is a distribution of total cost growth from Milestone II and adjusted for inflation and production quantity changes. A cost growth factor less than one would indicate that a program was overestimated; while a factor greater than one indicates that a program was underestimated. The data show the mean of these programs to have a total cost growth of 1.44 based on adjustments to Milestone II quantities, demonstrating a clear bias toward underestimating a program's cost at the time of Milestone II.

Cost estimates carry with them a large degree of uncertainty, and it is this uncertainty that is a contributing factor toward an inaccurate estimate [9]. While analyzing 11 MDAP programs that showed significant cost growth; the Institute for Defense Analyses (IDA) determined that "weaknesses in initial program definition and costing" along with "weaknesses in management visibility, direction, and oversight" were major causal factors [6]. The IDA report illuminates the fact that this uncertainty in the estimate will inevitably be visible in a program's cost growth by stating, "If a program's initial cost estimate is erroneously low, future cost growth is virtually assured [6]." WSARA seeks to provide tools with

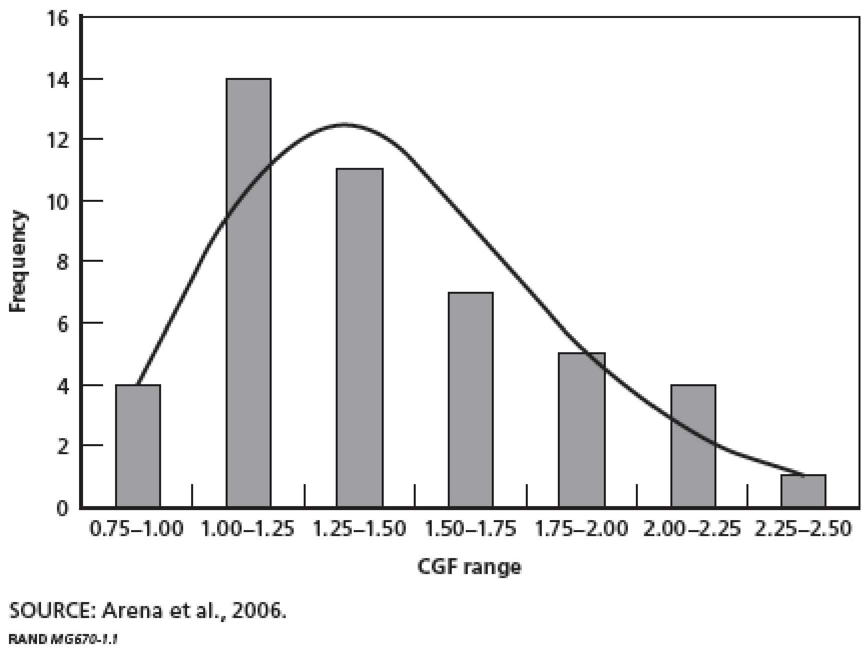

Figure 1: Distribution of total cost growth from Milestone II (adjusted for quantity changes and inflation).

which cost estimators may combat this uncertainty with policies emphasizing a renewed focus in early systems engineering. One such policy is the WSARA 2009 mandate that MDAPs use competitive prototyping as a means to ensure competition. In section 203 WSARA states:

> [T]he acquisition strategy for each major defense acquisition program provides for competitive prototypes before Milestone B approval … unless the Milestone Decision Authority for such program waives the requirement… [10]

This policy has been put into effect in order to improve contractor performance throughout a program's life cycle. By instituting competitive prototyping early in the acquisition process, this policy could potentially assist cost estimators in making more accurate assumptions in their estimates. If a competitive prototype does occur prior to MS B will it affect the deviation between actual research and development and production costs from the cost estimate submitted at MS B? This research paper attempts to quantify the benefit of prototyping prior to MS B by analyzing cost growth after MS B.

Research Focus

The Aeronautical Systems Center has sponsored this research to determine the effects current policy is having on the cost estimation process and life cycle costs for defense acquisition programs. This research paper will begin this process by examining the quantitative benefits of prototyping early in a fixed-wing aircraft acquisition program, and compare the cost estimates of these programs against programs that did not have technology demonstrators or prototypes prior to MS II or MS B.

For this research, an early prototype is hardware used for testing, that was built before full scale development (FSD), engineering and manufacturing development (EMD), or system development and demonstration (SDD) began. The purpose of the prototype is to gain knowledge about the feasibility of technology, validity of requirements, operational suitability of a concept, and/or resources required to develop and produce a concept. In summary, the purpose is the reduction of risk and uncertainty for a future program. One thing that should be kept in mind is that not all prototype efforts should be successful in fielding a weapon system. If a prototype reveals a previously unknown technical problem, invalid requirement, or unaffordable resource commitment then the prototyping program was a success. Armed with the knowledge gained by the prototyping effort, decision makers can make an informed (hopefully better) decision about the DoD acquisition portfolio.

Research Hypothesis and Investigative Questions

This research started with expectations to show lower cost growth for programs that used early prototyping prior to FSD. The authors also sought to find out if any cost growth trends could be identified relating to schedule length, schedule growth and the cost of the prototyping phase in comparison to the program costs.

Methodology

To answer the question on the benefits of prototyping to cost estimation, 11 fixed-wing aircraft programs with either a prototyping or technology demonstration phase prior to commitment to full scale development were selected for analysis based upon the preceding definition of prototyping (see Appendix B). Cost data was gathered primarily from the Selected Acquisition Reports (SARs) [11] for each program. For this research, only research, development, test and evaluation (RDT&E), procurement and military construction (MILCON) costs were considered. A program's operating and support costs were not considered. Initially, the analysis was intended to compare the cost growth of these prototyped programs to the cost growth documented in [8]. This required determination of cost growth from the MS B or MS II decision. The cost estimate of the first SAR following the milestone review was considered to be the estimate to compare to the costs recorded on the final or latest SAR. After reviewing the list of prototyped programs, several were found to be amongst those included in the study of comparison [8]. There was also concern that only a small portion of the programs included in the contrasting study were fixed-wing aircraft programs. So, although the prototyped programs' cost growth data were compared to the cost growth factors (CGFs) shown in the study by Arena, et al. some additional cost growth factors were calculated for several non-prototyped fixed-wing aircraft programs as well for the purposes of comparison (see Appendix C). Cost growth factors were normalized for quantity changes and inflation.

Assumptions/Limitations

The time allotted to complete this study did not allow a thorough search for sources of cost estimates and actual costs incurred from other than the SARs. Therefore, programs that pre-date the publishing of SARs (1969) could not be included in the sample.

In addition to comparing the MS B or MS II cost growth to the cost growth documented by Arena, et al., there was also a desire to compare the cost growth from the time of the Preliminary Design Review (PDR) to the cost growth from the MS review. However, it was found that determining the date of PDR was not possible for many programs. For the programs that did have PDR dates available many of the dates were within months of the MS decision so there was not a separate cost estimate associated with PDR. Ultimately only three programs had a PDR date that was confirmed to be at least a year different from the date that the program met with the milestone decision authority (MDA) for a MS II or MS B decision.

II. Literature Review

Cost Growth

Cost growth in weapon system acquisition has been a consistent critique of the Department of Defense and the Services. Disappointed with continued poor performance with respect to acquisition program cost and schedule, Congress enacted the WSARA of 2009 [12]. WSARA includes provisions to ensure programs are based on realistic estimates and that programs can be cancelled for high levels of cost growth. However, cost growth in weapon systems procurement has a long history that predates WSARA and instigated the original DoD 5000 Directive and Instruction in 1971. Many studies have sought to describe trends and identify the sources of weapon system cost growth; the findings are summarized below.

The basic trend in cost growth can be summed up with one word – consistency. Studies that looked for trends across acquisition programs and within acquisition programs since the inception of the DoD 5000 have shown no real improvement in cost growth. In fact, research shows that "cost growth was higher during the late 1960s, lower in the early 1970s and higher in the late 1970s [4]." Drezner, et al. came to the conclusion that "no substantial improvement in average cost growth" had occurred over the three decades leading up to 1993 [13]. In a more recent study, the authors found that "development cost growth in the past three decades has remained high, with no significant improvement [14]." But, they did find greater variability in development cost growth during the 1990s.

In addition to cost trends across programs, Arena, et al. examined the cost growth trend over time within programs. As expected, they found the CGF tends toward 1.0 and the variability decreases as a program matures [8]. However, the authors also showed that the CGF does not settle to an average of 1 for the programs considered until 70-80% of each program had been executed from the time of MS II to the end of the program as indicated on the final SAR. Younossi, et al. found that development cost growth increased sharply up to about 40% of the time lapse between MS B and the costs published in the final SAR followed by shallower cost growth throughout the remainder of the program to include the procurement phase [14]. The same study revealed that procurement cost growth was steepest for programs up to approximately 40%t of the actual schedule between the MS B date and the date of the final SAR.

The actual cost growth factors reported in the various studies are not always consistent even though the studies consistently show a cost growth phenomenon. The reason for the differences seems to be related to a few factors: (1) some studies only include completed acquisition programs which have recognized all their cost growth in contrast to studies that included on-going programs, (2) differences in how the quantity normalization was accomplished, and (3) differences in the type of programs examined (e.g., space systems, aircraft, helicopters, etc. [8]). In [13], the weighted average total program cost growth was shown to be about 20%t from both the planning and development baselines. A decade later, McNicol found that 30% of the major systems in the DoD acquired between 1970 and 1997 showed negative cost growth (the cost had been over estimated) [15]. Further, of 138 systems examined, about 80%had a cost growth less than 30%. Approximately 20%of the systems had a cost growth of more than 30%. The authors of [8] found an average adjusted total cost growth for a completed acquisition program was 46% when measured from the MS II estimate. Arena, et al. also found that procurement cost growth was 44%and development cost growth was almost 60%. Finally, they showed that most of the average cost growth was due to relatively few systems that experienced extreme cost growth just as McNicol had shown previously. Table 2.1 in [8] provides an extensive overview of cost growth factors from studies examining cost growth prior to 2006.

As was mentioned earlier, the purpose of many studies was to identify the causes and consequences of cost growth. One of the most consistently cited reasons for increased cost in acquisitions is program schedule growth or extended programs [4] [14] [15] [16] [17] [18]. Reference [13] showed mixed results with regard to schedule. Drezner found no correlation between schedule slip and cost growth, but did find that longer programs have greater cost growth. In [4], Tyson, et al. stated that production stretch increased cost growth by 7 to 10%per unit increase in schedule stretch. Bolton, et al. attributed 9%of cost growth, on average, to schedule changes [18].

Another instigator of cost growth that receives much scrutiny is overly optimistic cost estimates early in a program. Several studies have claimed that cost estimates were often unrealistic and that independent cost estimates are needed to combat cost growth [15] [16] [18] [6] [17] [19]. Bolton, et al. cited errors in cost estimation to account for 10%of cost growth experienced by 35 MDAPs [18]. In [6], Porter, et al. mentioned that highly optimistic assumptions about the cost-saving benefits of acquisition reform initiatives were to blame for some cost estimation errors. They also pointed out that program offices and the services have a detrimental tendency to match their cost estimates to the expected funding available for a program. In [5], Lorell and Graser specifically addressed acquisition reform which will be touched upon later. O'Neil introduces the term “planning fallacy” to account for the overly optimistic estimates of what a program can accomplish. Planning fallacy refers to the “pervasive human tendency to hold ‘the conviction that a current project will go as well as planned even though most projects from a relevant comparison set have failed to fulfill their planned outcomes.’” Planning fallacy often occurs at multiple layers of decision making within the acquisition system [19]. Along with Porter, et al. [6], O’Neil suggested that an over reliance on contractor cost estimates can lead to unrealistically optimistic initial program estimates. He asserted that contractors often promise too much because the “incentives weigh heavily on the side of accepting future risks rather than immediate ones.” In this case, the contractor can risk failure to be selected for a program by providing a more realistic view of the resources required, which could lead to corporate suicide, or fight to be selected for a problematic program that will keep the company in business. The errors in cost estimation impacted programs with an effective 2 to 8%annual tax on procurement according to McNicol [15].

A few studies categorized the causes of cost growth. McNicol used decisions and mistakes to bin cost growth. He found that decisions accounted for 21 and 10%of cost growth from MS II during development and procurement, respectively, and mistakes were attributed with 24 and 18%of cost growth for development and procurement, respectively [15]. Similarly, Arena, et al. considered economy-driven and customer-driven variables to classify cost growth sources [20]. This study found that labor, material, equipment and manufacturing helped increase the cost of fixed-wing aircraft about 3.5%annually and accounted for one-third of cost escalation. Customer-driven factors accounted for two-thirds of the contribution to cost escalation. Production rate and technical complexity were chief drivers of customer-driven factors. Finally, Bolton, et al. grouped SAR variances into the following: (1) errors in estimation and planning, (2) decisions by the government, (3) financial matters, and (4) miscellaneous sources [18]. The authors found total cost growth to be dominated by decisions, which accounted for more than two-thirds of the growth. Interestingly, the decision category was similar to the customer-driven category defined by Arena, et al. and the proportions of cost growth were nearly equal. The primary factors within the decision category were quantity changes (22%), requirements growth (13%) and schedule changes (9%). As mentioned previously, cost estimation was blamed for 10%of cost growth in the error category.

Lorell and Graser suggested three types of acquisition reform:: reducing regulations and oversight, using commercial-like program structures, and multiyear procurement. They found that only the state of regulation and oversight following the Federal Acquisition Streamlining Act of 1994 correlated to program savings (on the order of 3 to 4%) [5]. They also stated that multiyear contracts may save about 5 to 10%on production contracts, which agrees with the findings of Tyson, et al. [4]. Lorell and Graser were unable to identify cost estimating relationships for any acquisition reform cost savings. They also felt there were too many caveats for the use of commercial-like practices to make a definitive statement about its benefits.

Another source of cost growth regularly reported in the literature is requirements growth or changes, unrealistic requirements (or at least unexamined for cost effectiveness) and requirements that are not matched to available resources [15] [18] [6] [20] [21] [22] [23].

One strategy to address cost growth has received mixed reviews by previous studies—prototyping. Tyson, et al. found prototyping before full scale development had generally been successful [4]. A few years later Drezner, et al. showed that prototypes are associated with higher cost growth [13]. They did show that programs that used prototyping prior to starting EMD had lower cost growth than programs that prototype post-EMD. These programs were also two years shorter in duration on average than the post-EMD prototyped programs. However, they showed that procurement cost growth for aircraft was the same for both prototyping and non-prototyping programs. These results are interesting as one would expect early prototyping to increase the knowledge of the feasibility of a program yielding consistently lower cost growth.

Prototyping

The Defense Acquisition University defines a prototype as "an original or model on which a later system/item is formed or based [24]." Over the years, many studies have been conducted on the usefulness of prototyping in major weapon system acquisition programs. Specifically, the belief is that prototyping can be used as a tool in order to "obtain better information for EMD decisions and technical/schedule/cost risk reduction [25]."

Recently Congress and the DoD have introduced legislation that reforms the Defense Acquisition process. Two of their goals are to "improve the department's ability to balance requirements with resources and establish a stronger foundation for starting programs [26]." DoDI 5000.02 adds detail to WSARA's mandate of prototyping early in a program:

> The [Technology Development Strategy] and associated funding shall provide for two or more competing teams producing prototypes of the system and/or key system elements prior to, or through, Milestone B. Prototype systems or appropriate component-level prototyping shall be employed to reduce technical risk, validate designs and cost estimates, evaluate manufacturing processes, and refine requirements. [27]

A prototype phase within a program prior to EMD can prove essential to achieving both goals, and may also prove necessary in discovering "if the chosen concept can be developed and produced within existing resources [26]."

Prototypes can give the decision maker insight into technical risks and uncertainty that may arise within a program early on, so that steps may be taken to correct these issues before cost or schedule overruns occur. Additionally, competitive prototypes can be a means by which competition is extended deeper into the development cycle, while keeping costs under budget. This can lead to a more competitive contract environment. Ultimately, the goal of prototyping is to successfully resolve technical risk as early in a program as possible in order to reduce cost.

In 1991 IDA conducted a comparison of defense system programs. The study identified total development cost growth of prototyped programs was 17% compared to 62% for those without a prototype. Results were similar for production cost growth. Programs with prototypes demonstrated a 29% increase in production cost while those without ballooned to 55% [28].

Ten years earlier The RAND Corporation conducted a study between four airborne acquisition programs: the A-10, F-16, UH-60, and AH-64. This report identifies prototyping as a "risk reduction strategy," adding "if the new system involves much technical risk, a prototype phase can probably improve the efficiency of finding and correcting many of the inevitable design flaws [29]." The difficulty lies with correctly identifying the technical risk. This was an essential aspect to why the Light Weight Fighter program was prototyped. It was during the prototype phase of the Light Weight Fighter (later known as the F-16) that "the fly-by-wire control and autostabilization system was refined and proven to work [28]." If, however, the wrong risk is identified as a lynchpin risk then the incorrect system may be prototyped. This could have disastrous results.

If the wrong system is prototyped then the program could be set back months or years behind schedule. Additionally, vast amounts of money will be wasted, and the program decision maker could be making risk based decisions on a prototype that at best doesn't matter or at worse provides a false sense of knowledge security. This can lead to improper cost estimates that inevitably challenge a program. If, however, the correct system is identified and prototyped then decision makers could see a return on their investment in the form of cost growth control. "There are at least three ways in which the existence of a prototype phase might improve the ability to estimate future program costs, or to control subsequent cost growth: an improved database for estimation, fewer unexpected configuration changes, and use of fixed price contracts [29]."

A solid prototyping program can provide a database from which cost estimators may pull current and realistic data by which to more accurately estimate program costs. Traditional cost estimates are made by comparing similar programs and taking previous programs' costs to use as baseline estimates. For early estimations this will suffice, but as programs move forward more detailed program estimates become possible and critical. It is challenging, however, to find previous programs to act as baselines if the new program contains unique technical risks. Some analysts will argue that having an actual flying piece of hardware can bridge the gap between "similar" previous programs and a current program's estimate. "In the Light Weight Fighter program General Dynamics used data from their prototypes as a basis for cost estimates for the full scale development and production phases." Their prototypes gave "General Dynamics management an estimate of the labor hours, materiel costs and tooling that would be required to build their aircraft model using production line methods [29]."

A significant source of cost growth is the necessity to reconfigure a program in order to account for unexpected technical difficulties. "A prototype evaluation before FSD might reduce the number of corrective design revisions [29]" that can plague most development programs. The assumption here is that a flying test prototype will highlight many of the design changes that are necessary early on in a program. Discovering these changes earlier rather than later allows the developer to incorporate these changes into early full-scale development models, and avoid the growth in cost that would be caused by retrofitting these changes in later blocks. Additionally, "the FSD phase following a prototype phase is considerably shorter, on average, than it is in those programs that omitted a prototype phase [29]." Based on their analysis of the four programs in the 1970s, the report "suggests that the inclusion of a prototype phase does not usually extend the total development time [29]."

These previously studied articles would lead one to believe that prototyping is the answer to all of a cost estimator's problems. A perfect or one size fits all solution, but there are other articles that refute these claims. Stating, in actuality that "there are few significant differences between prototyping and nonprototyping programs with respect to cost growth, total actual program duration, or schedule slip [30]." Drezner goes on to claim that although "dollar-weighted average cost growth ratio for the prototyping programs is 1.30 while nonprototyping programs average 1.16…The evidence linking prototyping and program outcomes is fairly weak [30]." The author goes on to state that after studying 90 major weapon system acquisition programs "most of the differences between prototyping and nonprototyping programs were not significant from a statistical standpoint." This study highlights the importance of properly identifying a prototyping strategy. One that focuses less on the need to prototype, and more on identifying the technology challenges and high risk areas that should be prototyped. In the end a successful program may result more so because of this critical identification rather than just because the program was prototyped. This is very difficult to prove because it is so ambiguous. "We cannot know what the outcome of a prototyping program would have been if it was not prototyped; we can only speculate [30]." It is because of this difficulty that this study suggests that policy remain flexible with respect to prototyping.

So, does prototyping help cost estimation, or is it a waste of money? Perhaps the answer rests more firmly with specifically *what* is prototyped rather than whether prototyping occurred. Program decision makers must decide whether a prototype is appropriate and cost effective. Clearly programs with unique technological risks involved could stand to benefit from a prototype phase prior to FSD, especially if a program is attempting to leverage immature technologies. In the 1970s, the HAVE BLUE program "demonstrated that a manned aircraft could achieve radar signatures low enough to conceivably perform tactical missions without being detected [31] [31]." The success of this prototype is not only measured within the F-117 program but throughout descendant programs within the DoD, making the measurement of success less quantitative and more qualitative. This demonstration allowed the program to move forward under a strong foundation that the technology was ready and could achieve the requirements of the program. Additionally, the Advanced Medium STOL Transport (AMST) program provided "a wealth of practical experience and engineering data on large [short takeoff and landing] (STOL) tactical transports and operational employment." It also "gave insight into the costs of developing such an aircraft for production in the event that a program should be pursued in the future [32]." It was because of the fact that the AMST program honed in on the STOL requirement that allowed the prototypes to focus on the aspects of the technology that would allow the program to be successful. In this case the correct technology limitations were both identified and prototyped. Both prototypes focused on the engines and powered lift design. This would ultimately enable the successful achievement of the STOL requirement, and make the "AMST program a vital step in developing the technology that made the C-17 Globemaster III possible [32]."

Historically, emphasis on prototyping has "waxed and waned throughout the Air Force [33]." When selecting the best strategy for moving forward with a major weapon system acquisition, program leadership will debate the benefits of a prototype. There is much literature available to add guidance on the merits of prototyping, but depending on what is researched the results seem to vary. The literature studied for this project; however, all seem to agree that if a program is to move forward with a prototype phase prior to FSD understanding what needs to be prototyped is critical. The challenge for program managers is to "clearly focus on end product objectives, and then conduct technology demonstrations that provide the essential information for these systems [33].” Ultimately this is the driving force behind a program’s success or failure. None of the literature found has tried to address the issue of prototyping in the last decade, when systems have become increasingly complex. Much of the literature has based their results on limited numbers of programs during a similar time frame, or on large numbers of data pulled from multiple major weapon system acquisition programs throughout the DoD that have few similarities. They all seem to agree that there might be an ambiguous benefit to prototyping, but based on these readings it is difficult to quantify exactly what should be prototyped, or what if any influence prototyping ultimately has on the success or failure of an acquisition program.

Summary

As stated, “cost growth acts like a tax, squeezing all acquisition programs and causing inefficiencies [17].” Studies have shown that cost growth is a persistent problem for the DoD that spans decades. Poor estimates, requirements instability, program delays and numerous other causes have been cited for cost growth. Ultimately, the blame for most cost growth can attributed to poor decision making, particularly at the inception of many programs. Generally, decisions are only as good as the knowledge available to support the decision. Some programs have no doubt been initiated against better judgment or in disregard of the gaps in knowledge about the magnitude of the challenge presented by a program. WSARA and DoDI 5000.02 have placed renewed emphasis on prototyping in the hopes that it will support knowledge based decision making, and ultimately resolve technical risk as early in a program as possible in order to reduce costs or at least cost growth.

III. Methodology

Cost growth was determined based on cost estimates and actual costs reported in a program's SARs. Costs reported in each program's SAR associated with MS II (or MS B) were gathered and then compared to the base-year cost data found in the program's final or latest SAR. In a few cases, prior to the mid-1970s, cost data available in the SARs were only presented as then-year dollars. Also, most of the more recent programs experienced base-year changes between the MS II or B estimate and the final or latest SAR. For these instances, the data were inflated from then-year dollars or from the base-year on the SAR associated with the MS decision to the base-year used on the final or latest SAR. Then-year dollars were converted by using the weighted indices, and the base-year dollars were inflated by using the raw indices of the OSD inflation tables [34] [34] [34] [34] [35] [35]. This approach removes the majority of inflation related cost growth, which is common practice in studying cost growth.

Once the results of inflation had been removed from the data there was still an aspect of growth related to procurement quantity changes between the MS II or B estimate and the final or latest SAR. To remove the effects of quantity changes, all the SAR procurement cost estimates were adjusted to the MS B or II quantity estimate. The adjustment uses a cumulative average cost improvement curve (CIC) derived from annual funding data provided in each program's SAR. The recurring and non-recurring costs must be separated for each year of funding, accumulated year by year and then plotted against the cumulative quantity procured for each year to develop the cumulative CIC (also known as a learning curve). This methodology is described by Hough in [36] and in greater detail by Dews, et al. in Appendix A of [37]. If the production estimate at the milestone review was greater than the number of aircraft actually built then the cost of purchasing the un-built aircraft that were included in the original estimate were added to the procurement cost of the program. Likewise, if the production estimate was lower than the actual production run then the cost of the additional aircraft were subtracted from the final cost of the program. This methodology differs slightly from what was used in the comparison study because Arena, et al. normalized the cost data to the final quantity produced. However, Appendix C of [8] presented the data for normalization to the MS II quantity. So, a direct comparison of CGFs is possible between the two studies.

Figure 2 shows the amount of total cost removed or added (as in the case of the example in the figure) to the current estimate (CE) based upon the difference between the quantity planned at the time of the development estimate (DE) and the quantity actually procured or planned at the time of the CE. This quantity normalization method provides a consistent basis for normalization as the planned quantity at MS II or B does not change, unlike the quantity of the current estimate which can change from SAR to SAR. For the example below, if the program had procured the number of aircraft that were planned at the time of MS B then the total program cost would have increased significantly over the cost reported in the CE. So, calculating a CGF based on the DE created under the assumption of a large total quantity and the CE based on a much lower actual total quantity is distorted, appearing to be much lower than what an honest assessment of the program cost would show.

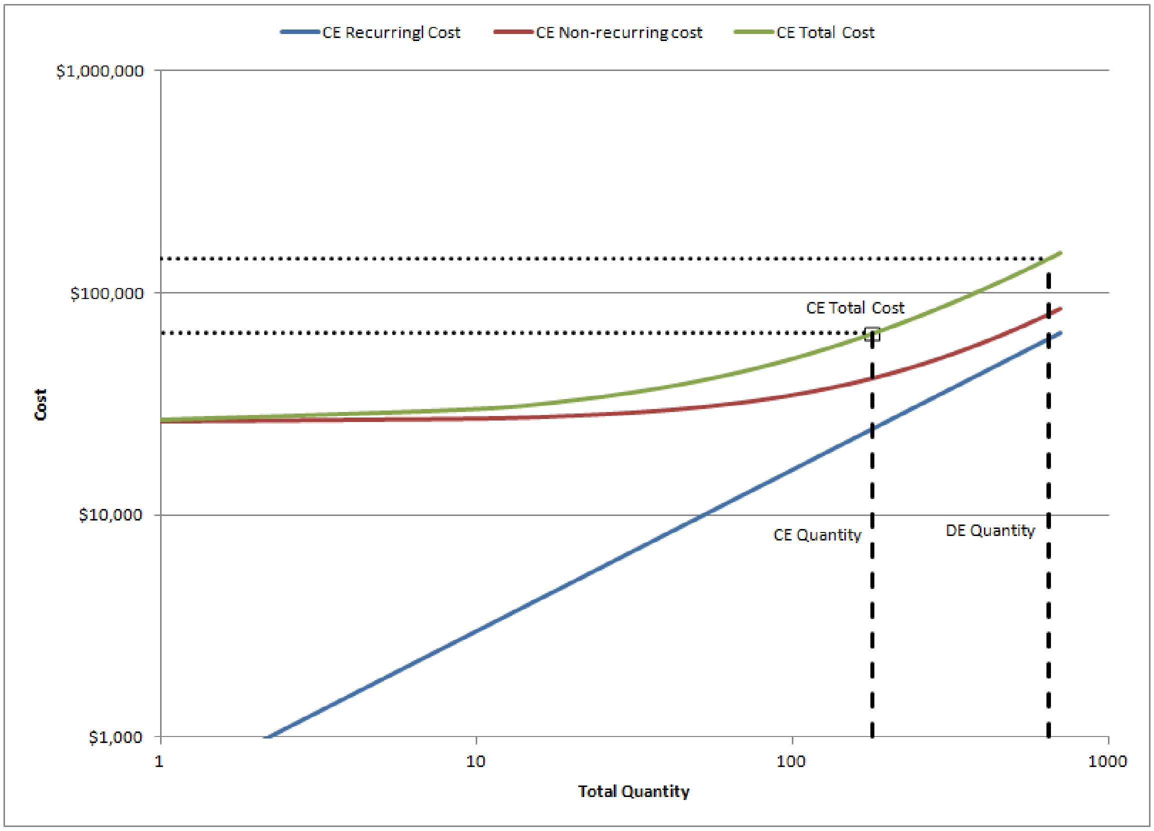

Figure 2: Quantity normalization is accomplished by removing the difference between the cost estimate at the DE quantity and the CE quantity on the total cost curve (recurring plus non-recurring cost) for the current estimate.

A few of the older programs used in the study had 'non standard' cost data available (by current SAR standards) when compared to the other programs used in the study. The first of these programs was the A-10. The data available for the A-10 did not allow the separation of the recurring and non-recurring costs. Therefore, a CIC could not be determined. In the case of the A-10, the final procurement quantity was 727 aircraft, and the MS II planned quantity was 729. Although this is a small change, the quantity cost variance contained in the final SAR was used to normalize for the quantity change. This same problem arose for some of the programs used as comparison non-prototyping programs, and these cases were resolved in the same manner (see Appendices B and C).

The F-117 program also presented some difficulty in determining a CIC. The data obtained from SPO documentation did not provide a year by year breakdown of RDT&E costs. However, recurring and non-recurring costs for procurement were available by fiscal year in then-year dollars. The RDT&E costs through FSD were provided in then-year dollars as a lump sum. Additionally, the cost of full capability development was available in then-year dollars as a lump sum. Full capability development was the RDT&E that continued after the completion of the FSD contract, which ended in July 1984. In [31] [31], the authors stated that full capability development occurred through approximately 1990. Procurement did not start until FY80. So, for this study the RDT&E costs were distributed from FY79 through FY90 according to power curves fit to the first 5 years and the following 6 years of RDT&E annual cost data from the A-10, F-16 and F-18 programs combined, which occurred during a similar time period and are all fighter/attack aircraft programs. As noted in [31] [31], the RDT&E spending profile for the F-117 was a bit unusual due to the structure of the program and the amount of development that occurred after the FSD contract completed. Once the RDT&E spend profile was determined, the CIC was calculated as discussed previously.

After calculating the average CGF for the sample programs a test of statistical significance was conducted on the mean as discussed in [38]. The significance testing was accomplished for the log normal distribution discovered by Arena, et al. in their study. Based on the findings of Arena, et al. the distributions of the data gathered for this study were assumed to be log normal as well. Using the equations for the log normal mean and variance defined in [39, p. 625] the mean and variance for log space were calculated for the data presented in Tables C.1 and C.2 of the comparison RAND study.

IV. Analysis and Results

Overview

In this chapter, the authors analyze the CGF and SAR data of 11 programs that contained a prototype phase prior to FSD. This data is then compared with the cost growth data collected by Arena, et al in [8] to identify what, if any, influence prototypes have on cost growth in an acquisition program.

Results

Initial Findings

SAR cost data is typically presented under the following categories: development (RDT&E), procurement, military construction (MILCON) and total cost. Additionally, there are operations and maintenance costs related only to the acquisition portion of the program. As described in the previous chapter, the authors calculated CGFs adjusted for quantity change based on MS II (or B) SAR quantity estimates. Table 1 is a summary of the statistical totals for all 11 programs studied.

Table 1: CGF Summary Statistics by Funding Categories for MS II

Category	Number of Programs	Mean	Median	Standard Deviation	Minimum	Maximum
Total	11	1.52	1.42	0.43	0.97	2.40
RDT&E	11	2.15	1.54	1.15	1.32	5.04
Procurement	11	1.43	1.36	0.39	0.89	2.03

The table shows the mean total CGF to be greater than that of 1.44 established by the comparison study [8]. At first glance there does not seem to be a relationship between reduced cost growth and prototyping. An important observation, however, is that the data appears to be skewed because the mean is higher than the median for all categories. One of the reasons for this skew is the performance of the UAV programs. As an example the Predator program performed very poorly with an RDT&E CGF of 5.04 and a total program CGF of 2.12. This could be attributed to the fact that the Predator RDT&E spending profile was opposite that of most of the other programs. This program had more of a building block approach to RDT&E spending, with almost 50% of the total cost of RDT&E occurring in the last three years of a 13 year schedule. Figure 3 shows the distribution of the total CGF for the 11 programs studied. The distribution portrays the existence of two outlier programs, in this case Predator and Global Hawk, with total CGFs of 2.12 and 2.40 respectively.

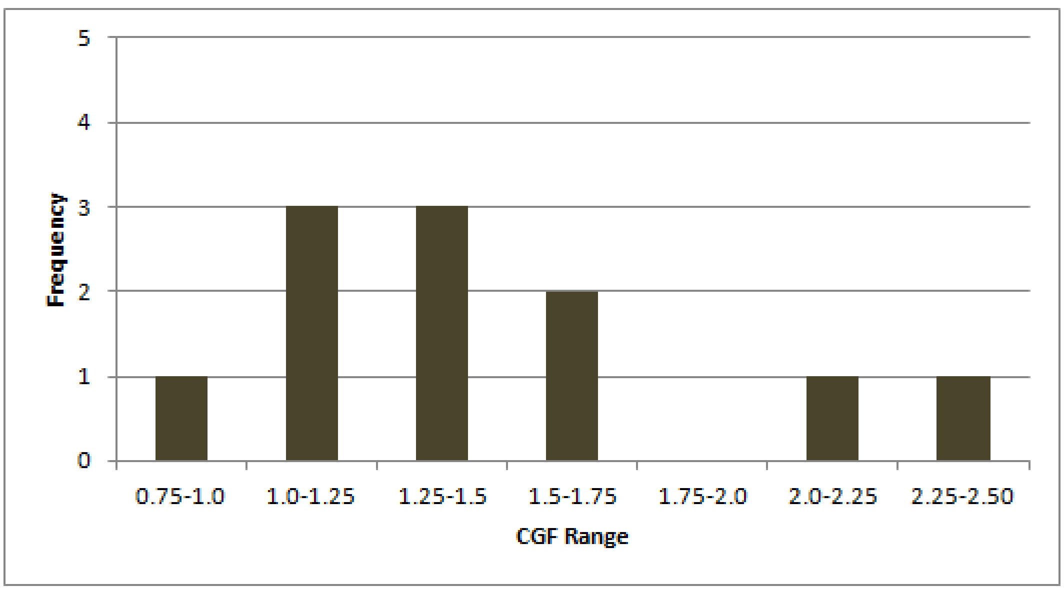

Figure 3: Distribution of Total Cost Growth from MS II Adjusted for Quantity Changes

In order to better evaluate the performance of this data, a deeper analysis is required. The data in Table 1 includes the entire F-16 program. In order to more accurately assess the cost growth in the F-16 program the authors were able to separate the cost growth due to the F-16C/D models from that of the F-16A/B models. This is a more fair assessment of the program, because one could argue that at the time of MS B those estimating the cost of the program were not planning for the F-16C/D versions. Removing the F-16C/D models from the analysis improves the F-16 total CGF from 1.42 to 1.11; a significant decrease and a much more accurate assessment of the cost growth based on the MS B estimate. Table 2 depicts the same basic data as Table 1, but this time the cost growth due to the F-16C/D model is removed for analysis.

Table 2: CGF Summary Statistics with F-16C/D Removed

Category	Number of Programs	Mean	Median	Standard Deviation	Minimum	Maximum
Total	11	1.49	1.31	0.45	0.97	2.40
RDT&E	11	2.05	1.54	1.17	1.32	5.04
Procurement	11	1.41	1.36	0.41	0.89	2.03

Table 3: CGF Summary Statistics with F-16C/D & UAV Programs Removed

Category	Number of Programs	Mean	Median	Standard Deviation	Minimum	Maximum
Total	9	1.32	1.25	0.26	0.97	1.72
RDT&E	9	1.57	1.45	0.33	1.32	2.33
Procurement	9	1.27	1.13	0.30	0.89	1.69

While the results in Table 2 are more favorable, the two UAV programs are still heavily influencing the data. The results in Table 3 are much more interesting. Here the total CGF due to removing the two UAV programs has been reduced to 1.32. Initially this appears to be a large improvement, but conducting a statistical test on the mean of these data results in a P-value of 0.214 when compared to the data from Arena, et al in [8]; meaning that there is a 21.4% chance that the null hypothesis that the mean for total cost growth of the prototyped programs is equal to the cost growth found by Arena, et al. is true. Based on these results the null hypothesis cannot be rejected. So, it would be inaccurate to conclude that prototyping definitely limits cost growth in all programs. The

P-value associated with procurement cost growth compared to the research of Arena, et al. was 0.139.

Expanded Results

After a closer look there were four programs included in both studies: the A-10, AV-8B, F-16 and F-18. Additionally, Arena, et al included a variety of weapon systems that were not fixed wing aircraft ranging from the MILSTAR satellite to the M-1A2 Abrams tank. In an effort to compare like systems and to separate the cost data from programs that were in both studies, SAR data was collected from fixed-wing aircraft that did not have a prototype phase prior to FSD. This creates a data set that can be analyzed to compare cost growth specific to fixed-wing aircraft acquisition programs only. A total of 19 programs were used dating back to 1963 (See Appendix C for complete list of programs). The results were captured and studied in the same manner mentioned in the previous chapter. Table 4 summarizes the CGF categories for these 19 non-prototyped programs.

Table 4: CGF Summary for Non-Prototyped Fixed Wing Aircraft Programs

Category	Number of Programs	Mean	Median	Standard Deviation	Minimum	Maximum
Total	19	1.36	1.31	0.34	1.00	1.99
RDT&E	19	1.36	1.22	0.39	0.91	2.16
Procurement	19	1.33	1.25	0.34	0.96	2.00

The results in Table 4, when compared to Table 2 offer evidence that prototypes may not have a direct influence on a program's cost growth. It is important to note, however, that many of the programs selected in the non-prototyped data set were programs that were modification programs. One would expect that a program based on modifying a current airframe would show significantly less cost growth. If these programs are removed from the study then the mean of the total CGF of non-prototyped programs goes up further to 1.48 while procurement CGF increased to 1.52. A robust increase from the data depicted in Table 4. However, based on hypothesis testing, it would still be inaccurate to state that prototyping improves a program's cost growth based on the samples at hand.

Figure 4 offers a comparison of RDT&E CGFs of the prototyped programs, as well as the prototyped programs after removing the two UAV programs, against the CGFs for the non-prototyped programs and against those same programs after removing the modification or derivative programs. This figure illustrates that of the original 11 prototype programs, CGFs of non-UAV programs are much lower than the prototyped program set as a whole. The figure also shows programs that were modifications or derivatives are significantly reducing the RDT&E CGF of the non-prototyped programs.

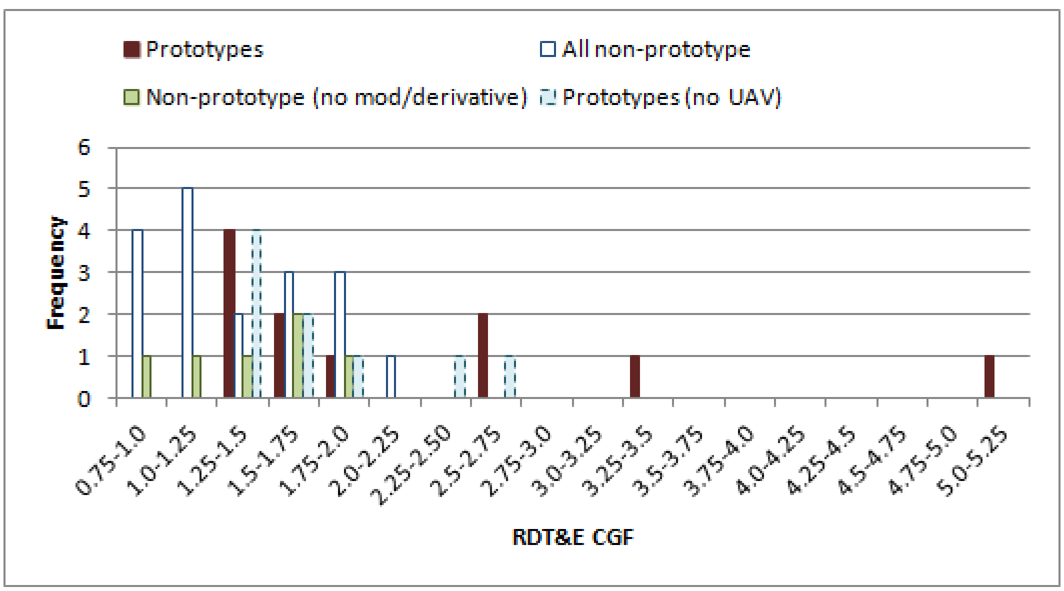

Figure 4: Distribution of RDT&E CGFs of prototyped programs, non-UAV prototyped programs, non-prototyped programs and non-prototyped programs that are not modifications or derivatives.

Figure 5 shows the same data for the procurement phase of each acquisition program and Figure 6**Error! Reference source not found.** does the same for total program CGF. Once again, the UAV programs are skewing the prototyped programs data set. UAV programs tend to increase the average CGF of those programs that used early prototyping, and those programs considered to be modification or derivative programs tend to decrease the average CGF of the non-prototyped programs.

To provide a comparison between like programs, another cost growth comparison was made between prototyped programs that are not UAV programs and are also not derivative or modification programs with non-prototyped programs that were not modification or derivative acquisition programs. Table 5 shows the summary statistics for these two data sets. The hypothesis test for mean total program CGF results in a P-value of 0.159 so the difference is not statistically significant. However, a test on the mean procurement CGF does reveal that the means are statistically different at nearly an $\alpha = 0.05$ level. So, it appears that early prototyping is beneficial for procurement cost growth control.

Table 5: CGF Summary of Non-Modification/Derivative Programs for Non-UAV Fixed-Wing Aircraft Programs that Used Early Prototyping and Non-Prototyped Programs

Categories	Number of Programs	Mean	Median	Standard Deviation	Minimum	Maximum
Total (prototyped)	8	1.36	1.28	0.24	1.19	1.72
Total (non-prototyped)	6	1.48	1.45	0.32	1.04	1.99
RDT&E (prototyped)	8	1.60	1.49	0.34	1.36	2.33
RDT&E(non-prototyped)	6	1.40	1.51	0.30	0.91	1.76
Procurement (prototyped)	8	1.32	1.24	0.28	1.04	1.69
Procurement(non-prototyped)	6	1.52	1.53	0.35	1.03	2.00

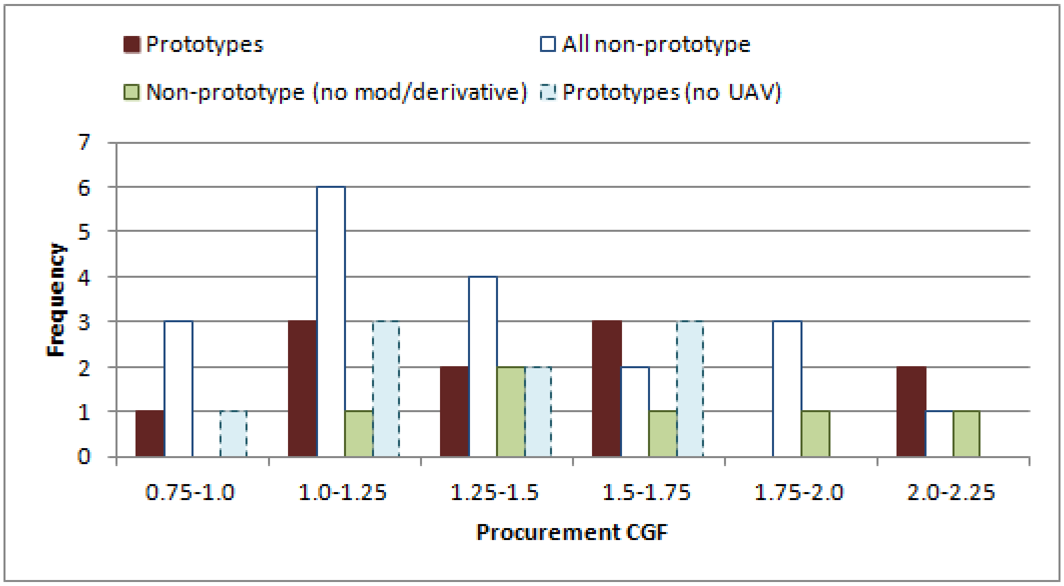

Figure 5: Distribution of procurement CGFs of prototyped programs, non-UAV prototyped programs, non-prototyped programs and non-prototyped programs that are not modifications or derivatives.

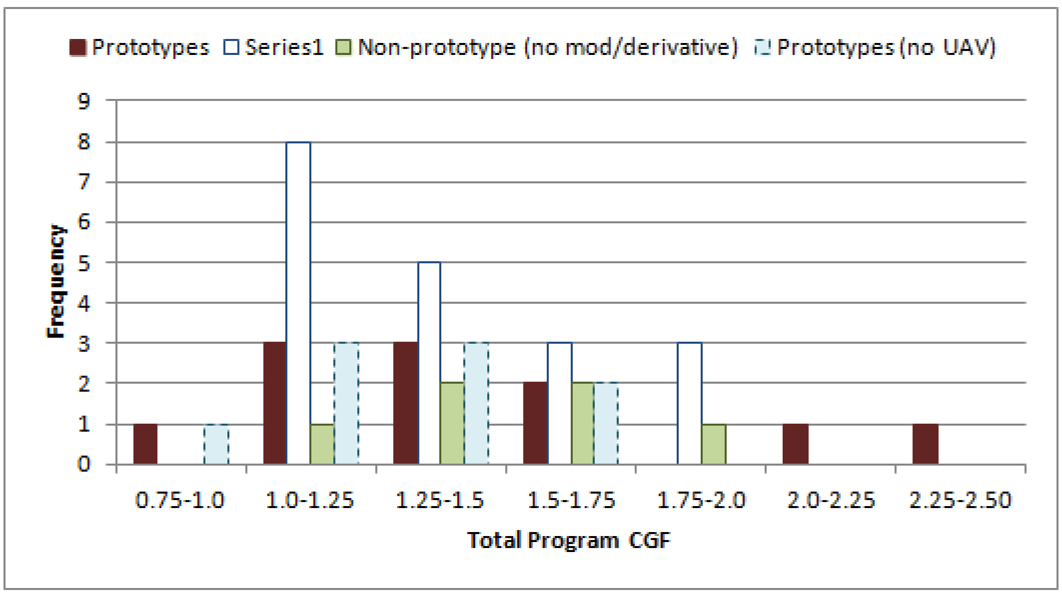

Figure 6: Distribution of total program CGFs of prototyped programs, non-UAV prototyped programs, non-prototyped programs and non-prototyped programs that are not modifications or derivatives.

Last, the CGF for fighter/attack aircraft was examined as these programs comprise the majority of both the early prototyped and non-prototyped program data sets. The summary statistics are shown in Table 6 and Table 7.

The mean of the procurement CGF for the fighter/attack aircraft programs that used early prototypes is statistically less than the mean CGF for the non-prototyped data set at the $\alpha = 0.1$ level. But, once again the difference between the means of the total program CGF is not statistically significant.

Table 6: CGF Summary for Early Prototyped Fighter/Attack Aircraft Programs

Category	Number of Programs	Mean	Median	Standard Deviation	Minimum	Maximum
Total	7	1.33	1.31	0.23	0.97	1.68
RDT&E	7	1.72	1.54	0.49	1.32	2.51
Procurement	7	1.28	1.33	0.28	0.89	1.69

Table 7: CGF Summary for Non-Prototyped Fighter/Attack Aircraft Programs

Category	Number of Programs	Mean	Median	Standard Deviation	Minimum	Maximum
Total	8	1.46	1.35	0.34	1.03	1.98
RDT&E	8	1.47	1.51	0.44	0.98	2.16
Procurement	8	1.44	1.37	0.30	1.06	1.90

The analysis shows that it would be inaccurate to assume that prototyping ensures a more accurate cost estimate across all acquisition programs. Prototyping does not appear to improve cost growth in either the RDT&E phase or for the total program. Prototyping does, however, appear show benefits in the procurement phase; giving programs with large procurement buys the opportunity for a return on investment. Program directors with an acquisition program expecting to purchase a high number of units, should strongly consider prototyping as a possible strategy.

Relationships Between CGF and Other Program Characteristics

Cost growth is not the only important aspect to analyzing the overall success of a program. Another important measure of effectiveness is schedule growth. Studies have shown that longer programs tend to have higher cost growth [8]. If this were accurate then programs with schedule slip would show extensive cost growth, but Figure 7 shows no discernible relationship between schedule growth to initial operational capability (IOC) and CGF for the fixed-wing aircraft programs that used prototypes prior to MS II or MS B. The Pearson correlation coefficient revealed very weak linear dependence between schedule growth factor (SGF) and CGF. Figure 8 also reveals no relationship between the CGF and the number of months that actually transpire between MS II or B and IOC for the set of programs that used early prototyping.

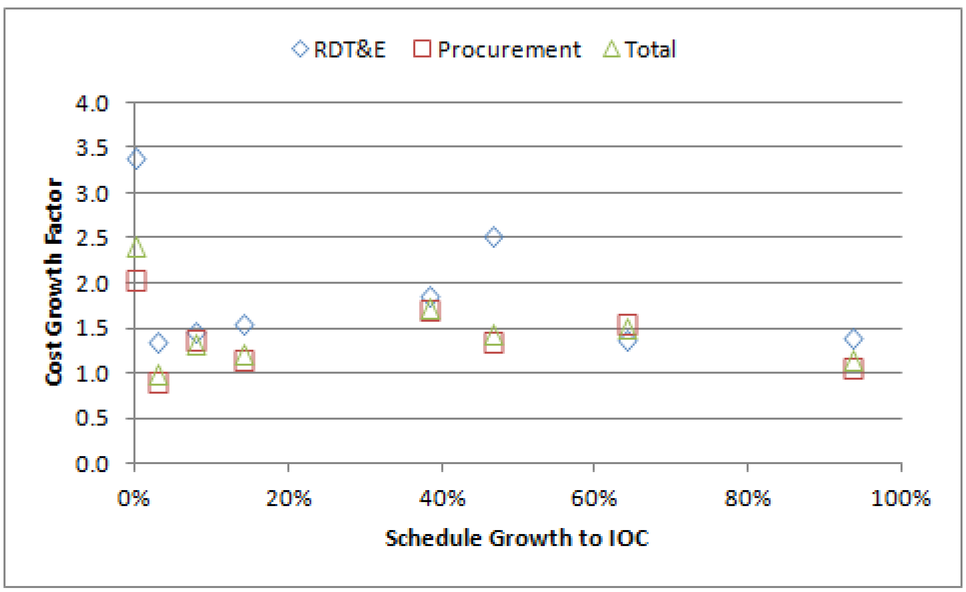

Figure 7: Relationship of a program's SGF to its CGF

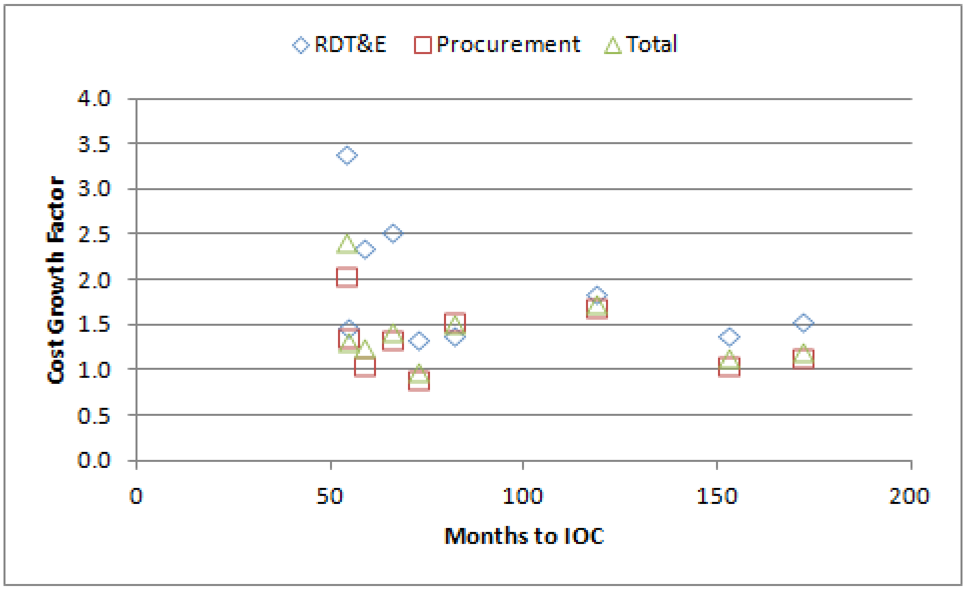

Figure 8: Relationship of a program's length of schedule to IOC to its CGF

The next relationship examined was between CGF and the proportion of program costs that were spent during the early prototyping phase. The proportion of program's cost was calculated by first removing the cost of the prototype phase from the RDT&E cost. Then the prototype phase cost was divided by the remaining RDT&E cost and by the remaining total program cost. Figure 9 displays the percentage of RDT&E spent on the prototype phase and relates it to the program's RDT&E, procurement and total CGF. Figure 10 portrays the prototype cost as a percentage of the entire program's cost and relates this to the individual CGFs. In both cases, no discernible relationship exists and once again the Pearson correlation coefficient reveals only weak linear dependence. Contrary to what one might expect, programs that spent a small proportion of funds on early prototyping seem to fair just as well as programs that spend more on the early prototyping phase.

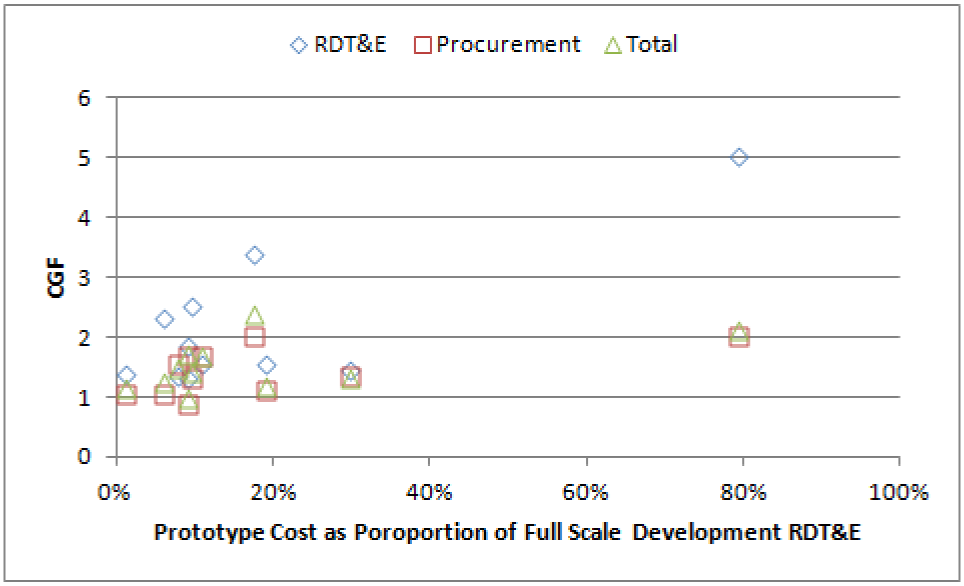

Figure 9: CGF related to the proportion of RDT&E funds dedicated to early prototyping

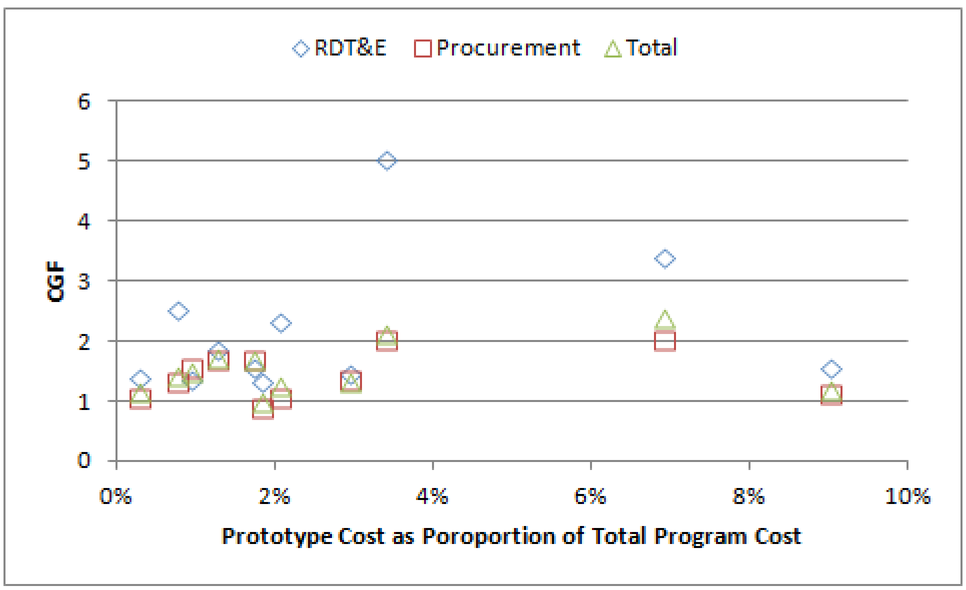

Figure 10: CGF related to the proportion of total program cost dedicated to early prototyping

Summary

There is little evidence that on average early prototyping is any more effective at controlling cost growth than other acquisition strategies. The only caveat to this statement is when UAV programs are not included in the discussion then early prototyping does appear to lead to lower procurement and total cost growth for the follow-on acquisition program. The data were also analyzed in the hopes of finding relationships between cost growth and other program characteristics. However, no relationship between CGF and SGF, schedule length or the proportion of program costs expended during the early prototyping phase exist.

V. Conclusions and Recommendations

Conclusions of Research

Early prototyping is not a cure-all that guarantees success in acquisition with respect to cost growth. Early prototyping was, however, used for several successful fixed-wing aircraft acquisition programs. For these programs, prototyping has been counted among the reasons for the success of the acquisition program that followed. And, although the data did not present any statistically significant relationships for total program cost growth or rules of thumb for the use of prototypes as part of fixed-wing aircraft acquisition programs, there are still some insights that can be drawn from this research.

The prototype program structure or management style appears to have a strong bearing on the success of the acquisition program that follows just as an acquisition program's management structure is a determinant of performance [23]. The prototype programs executed during the 1970s (Close Air Support (A-X), Light Weight Fighter (LWF), Advanced Medium STOL Transport (AMST) and HAVE BLUE) had many similarities in program structure as described in their respective case studies [40] [41] [32] [31]. With the exception of the C-17A, all the acquisition programs that followed these prototyping programs experienced lower than average cost growth. By most accounts these prototype programs led to acquisition programs that were successful in delivering the performance required, and delivering an adaptable weapon system that went on to deliver performance well beyond what was envisioned at program initiation. The Advanced Tactical Fighter (ATF) program also used a similar prototyping program structure that was modeled after the lessons learned from these predecessors [42]. As mentioned previously, most of the acquisition programs that followed from these prototype programs performed well in terms of total acquisition program cost growth. This was primarily due to relatively low procurement cost growth.

Regarding the C-17, a case study of the acquisition program would be required to uncover the reasons for the higher than average cost growth. However, a few observations will show that the acquisition program did experience external factors that likely exerted a strong influence on the cost growth. One significant difference between the C-17 program and the programs that followed the other prototype efforts is the delay between the prototyping and acquisition programs. The AMST prototype program officially ended in 1979 (the test program was complete by early 1978), but the C-17 program did not start until 1985. The lengthy delay between prototype phase and acquisition program is not characteristic of the other programs. Also, in addition to underestimating the resources required for the program, the C-17 program experienced changes external to the program office and contractor in the form of requirements, funding and production stretch [43] [44].

Moving back to the topic of procurement cost growth, the other programs mentioned above showed lower than average growth (compared to the RAND study and the fixed-wing aircraft comparison samples) except for the F-18. However, most of these programs had higher than average RDT&E cost growth compared to the fixed-wing aircraft comparison sample. The lesson learned is that prototyping at the system level may be best applied to programs that expect a large production run.

The previously mentioned case studies provide some of the common features of these prototype programs that were described as contributors to success. Note that these are characteristics of the prototype programs, not necessarily the acquisition programs that followed. Program offices that are considering a prototype program prior to MS B would do well to examine the costs and benefits of these program features.

1. Small and empowered program offices (10s of people)
2. Minimum documentation requirements
3. Issued clear performance goals rather than specifications for compliance.
4. Contractors were allowed to make tradeoffs to provide best overall performance and demonstrate the technologies of interest
5. Contractors were allowed to create the schedule but were held accountable once the clock started
6. Prototypes were relevant to the follow-on acquisition programs in terms of risks addressed and the technologies that were included in the initial acquisition program that followed
7. Prototypes were relatively low cost and austere (only the A-10 and F-22 exceeded a prototype program cost of 10% of the acquisition program RDT&E)
8. Program office personnel maintained close communication (technical and programmatic) with the contractors, which provided insight rather than oversight
9. Testing was targeted to show evidence of meeting overall performance goals and the test teams featured combined developmental and operational testers from the government along with contractor test personnel. The test teams were also empowered to make in-scope changes to the test plan.

10. Contract structures allowed the contractors to take risks while protecting the government from cost overruns by using cost ceilings or fixed-price contracts (this falls in-line with the concept that some prototypes will fail, but measured risk taking should not be avoided)
11. The programs offered legitimate competition with no clear front runner at the beginning of the program and a significant prize to be won for providing the best overall design

Additionally, some of these programs used extensive subsystem prototyping and/or modeling and simulation to support the full scale aircraft prototyping program. Two examples of this are the A-X and ATF programs. The A-X program prototyped the gun system and ammunition while ATF pursued extensive avionics and engine development. These efforts were external to the competitive fly-off prototype programs. In both cases, the subsystem technologies were believed to be as high or higher risk than the technologies demonstrated on the aircraft prototypes.

The fixed-wing aircraft programs that have used prototyping most recently are showing poorer cost growth performance. Two of the three programs that kicked-off their prototyping efforts in the 1990s were UAV programs; the third was F-35. Both of these UAV programs used advanced concept technology demonstration (ACTD) programs. The data show that these programs had much higher than average cost growth, but the actual schedule from MS B to the end of initial operational test and evaluation (IOT&E) and to initial operational capability (IOC) declaration were relatively short compared to the other prototyped programs. So, this could be an indication that using an ACTD allows programs to buy a shortened schedule for UAVs. This conclusion is uncertain, however, since these also happen to be the only UAV programs in the study, and the only other ACTD program in the study is F-117. In the case of F-35, [16] and [45] provide several reasons that cost growth occurred.

Two of the documented root causes for the high cost growth of F-35 apply particularly well to prototyping. First, competing design requirements among the three variants of the aircraft were not discovered or sufficiently highlighted by the prototyping phase. One primary purpose of early prototypes is to prove the feasibility and utility of requirements and operational concepts, but the program must design test objectives that provide for collection of these data. Second, the demonstrators did not make use of key technologies to demonstrate capabilities. Early prototyping must be focused on demonstrating technology maturity *relevant to* achieving required capabilities on the follow-on weapon system. Prototyping the wrong technology will not contribute to good decision making with regard to committing to a weapon system and an accompanying acquisition strategy. Prototyping the wrong technology implies any of the following:

1. Technology incorporated on the follow-on weapon system is different or highly modified from what is demonstrated.
2. Avoiding high risk technology areas on the prototype.
3. Adding new high risk technologies after completion of the prototyping phase.
4. Ignoring integration of immature technologies (not addressing integration immaturity).

In summary, for F-35 the "concept demonstrator may not have been sufficient preparation for executing SDD [16]."

These thoughts lead to some remarks on acquisition policy. The WSARA 2009 makes competitive prototyping an expectation for MDAPs. The data in this study do not support such a strong mandate on the use of prototyping. Rather than forcing a program to pursue a waiver to avoid prototyping, programs should simply be required to examine the costs and benefits of prototyping prior to MS B. WSARA rightly points out that prototyping does not necessarily mean system level prototypes, but may be subsystem prototypes only. The cost-benefit analysis should be the required deliverable to the MDA at MS A. The difference in these approaches is the point of emphasis and the implied level of overhead for programs. Acquisition policy needs to emphasize accomplishing the analysis, which is part of sound systems engineering, rather than the paperwork trail. Unfortunately, the misplaced emphasis in WSARA was preceded by poor policy in DoDI 5000.02. As was quoted in Chapter II, DoDI 5000.02 clearly states that competitive prototyping will be used. Rather, the policy should require performance of a cost-benefit analysis of prototyping, state where findings will be documented, and describe example objectives of prototyping and prototyping strategies that program offices could consider. If a prototyping program is not designed specifically to meet objectives for a particular program it may well result in spending extra time and money up front with no recognizable benefits to the program later in the life cycle. Therefore, program managers need to target the prototyping to aspects of the program where knowledge is lacking most or risk is highest. An austere prototype with a properly focused test plan likely provides greater cost-benefit than a catch all prototype.

One other conclusion that can be drawn from the data presented is that, fixed-wing aircraft *modification* programs experience lower cost growth compared to new start programs. This should not be an earth shattering conclusion. The good cost growth performance of modification programs was previously noted by Drezner, et al. in [13]. The F-18E/F model is an excellent example. The modification of the F-18 from its original concept up to the E/F models has resulted in significantly improved product, but has retained its same basic design. This acquisition strategy resulted in a procurement CGF of 1.06 and total program CGF of 1.03! These results are vastly superior to similar new start programs during the same timeframe. The fact that these programs perform so much better than new start programs is not surprising; however, the benefits of pursuing a modification program may go underappreciated at times. Unless a weapon system is shown to be unsuitable for an emerging threat or mission area because of an inherent technology limitation (e.g., lack of low observable technology) then the services should strongly consider a modification program to fill new requirements and reserve new start programs for revolutionary or 'leap ahead' technologies. The F-117 and F-22 provide examples of revolutionary aircraft. In this case, obtaining a functional revolutionary technology application justifies the resources expended and the uncertainty of resource commitment (i.e., risk). A revolutionary technology application program provides the perfect example for extensive early prototyping.

The final lesson learned that this research identified is, for program managers and MDAs to review past, like programs to examine acquisition strategies that would be applicable to a new program. Although DoD 5000 provides an outline of required documentation to navigate the acquisition process, it is not designed (nor should it be) to provide a one stop shop of best practices that are most applicable to every type of acquisition program. Certainly the intent of DoD 5000 is to force programs down the path of best practices via the documentation requirements, however, this should not replace some independent study on past programs to uncover lessons learned. There are many pieces to an acquisition strategy (early prototyping being one) that should be examined for applicability as any new program is established. Discovering what worked, and possibly more importantly, the root causes of what did not work in past acquisitions might be one of the most important steps to establishing a successful acquisition program. MDAs would be wise to set the expectation that program managers show evidence of their technology maturity and integrated early RDT&E as they present an acquisition strategy for approval.

Significance of Research

This research shows that early prototyping may not be appropriate for all programs or it can be misapplied, resulting in prototyped programs that perform no better, with respect to cost growth, than programs that did not use early prototyping. Prototyping is not a panacea, and must be carefully planned and executed using lessons learned from past programs that implemented early prototyping successfully.

Recommendations for Action

Rewrite DoDI 5000.02 to emphasize the cost-benefit analysis of prototyping strategies and objectives. Program managers need to ask the questions, “How can prototyping help me make a better decision at MS B, and is the value of that knowledge worth the cost?”

Recommendations for Future Research

As this study progressed a suspicion arose that there may well be more to the story. A more complete description of the costs and benefits of early prototyping would be possible if completed weapon system performance were quantitatively described with respect to the performance planned at MS II or MS B. Additionally, tracking the progress of technology readiness levels throughout the prototyping phase provides another measure of effectiveness for early prototyping. Research of this nature would likely require more of a case study approach to each program examined. Finally, a case study approach into these prototyped programs is appropriate to reveal other program characteristics that contributed to cost growth (i.e., discovering root causes).

Secondly, the benefits of pursuing modification programs rather than new start programs could pose a profitable investigation. To be complete this would also require a study of the technologies along with the costs and schedule. As mentioned previously, the authors suspect that modification programs should be the first alternative to a material solution unless a prohibitive feature of the emerging need exists (e.g., the problem posed by anti-access threats to non-LO aircraft). An example of this would be to perform a cost-benefit analysis of modifying the F-22 rather than pursuing the development of the F-35 might reveal interesting results.

Summary

By using SAR data and historical program documents the authors were able to characterize the quantity and inflation adjusted cost growth for fixed-wing aircraft programs that used prototyping prior to MS II or MS B. The data show that, on the whole, prototyping did not lead to lower average cost growth. However, when UAV programs are removed from the data set, the average cost growth is lower than the average cost growth of the comparison sample sets. In this case, the difference was only statistically significant for procurement cost growth when compared to the fixed-wing aircraft programs that did not use early prototyping and were not modification or derivative programs. No relationship could be identified between the cost growth of these prototyping programs and proportional cost of the prototyping phase, schedule growth, or length of schedule. Two of eleven programs examined caused a significant increase in the overall average cost growth for the entire sample.

The language used in WSARA 2009 and the prototyping policy in DoDI 5000.02 are well intentioned but poorly written. Rather than encouraging programs to examine how early prototyping can benefit a program and to estimate the costs of these benefits, the policy simply says prototyping will be done in the Technology Development phase. WSARA does state that the prototyping requirement can be waived, however, pursuing a waiver is just another piece of unnecessary bureaucratic administration. Defense acquisition policy needs to emphasize how to use early prototyping to gain knowledge for making better decisions at MS B. MDAs should hold program managers accountable at the decision briefing by asking why particular aspects of an acquisition strategy were chosen, instead of using a waiver to show accountability.

Appendix A - Acronyms

AMST	Advanced Medium STOL Transport
CGF	Cost Growth Factor
CIC	Cost Improvement Curve
DoD	Department of Defense
EMD	Engineering, Manufacturing and Development
FSD	Full Scale Development
IDA	Institute for Defense Analyses
IOC	Initial Operational Capability
MDA	Milestone Decision Authority
MDAP	Major Defense Acquisition Program
MS	Milestone
PDR	Preliminary Design Review
SAR	Selected Acquisition Report
SDD	System Development and Demonstration
SGF	Schedule Growth Factor
STOL	Short Takeoff and Landing
UAV	Unmanned Aerial Vehicle
WSARA	Weapon System Acquisition Reform Act

Appendix B – Prototyped Programs Included in Study

Table 8: Prototype Programs Included in this Study

Weapon System	Prototype	Aircraft Type	ACTD	Derivative	Base Year	Quantity Norm Method
A-10	YA-10	Fighter/Attack	No	No	1970	SAR variances
AV-8B	YAV-8B	Fighter/Attack	No	Yes	1979	CIC
C-17A	C-15	Airlift	No	No	1996	CIC
F-16	YF-16	Fighter/Attack	No	No	1997	CIC
F-18A/B/C/D	YF-17	Fighter/Attack	No	No	1975	CIC
F-22	YF-22	Fighter/Attack	No	No	2005	CIC
F-35	X-35	Fighter/Attack	No	No	2012	CIC
F-117	HAVE BLUE	Fighter/Attack	Yes	No	2010	CIC
MQ-1	Predator	UAV	Yes	No	2008	CIC
RQ-4	Global Hawk	UAV	Yes	No	2000	CIC
V-22	XV-15	Airlift	No	No	2005	CIC

Appendix C – Non-Prototyped Programs Included in Study

Table 9: Fixed-Wing Aircraft Non-Prototyped Programs Included in the Study

Weapon System	Aircraft Type	Derivative	Base Year	Quantity Norm Method
F-18E/F	Fighter/Attack	Yes	2000	CIC
F-15	Fighter/Attack	No	1970	CIC
JPATS (T-6 II)	Trainer	Yes	2002	CIC
T-45	Trainer	No	1995	CIC
P-8	ISR	Yes	2010	CIC
MQ-4C	UAV	Yes	2008	CIC
B-1B	Bomber	Yes	1981	CIC
F-111A/C/D/E/F	Fighter/Attack	No	1963	CIC
EF-111A	Fighter/Attack	Yes	1973	SAR variance
E-6A	C2	Yes	1982	CIC
F-14A	Fighter/Attack	No	1969	CIC
F-14D	Fighter/Attack	Yes	1989	CIC
KC-10A	Tanker	Yes	1976	CIC
JSTARS	C2	Yes	1998	CIC
S-3A	C2	No	1968	SAR variance
C-5A	Airlift	No	TY*	SAR variance
A-7D	Fighter/Attack	Yes	1967	SAR variance
A-7E	Fighter/Attack	Yes	1967	SAR variance
E-3A	C2	Yes	1970	CIC
*The C-5 SARs did not provide base-year data. The then-year cost estimate was for the years FY65 to FY71 while the final estimate was for FY65 to FY74 (the FY74 budget was less than 1% of the total program budget). Since the data are not presented in the form of annual costs on the C-5 SAR the data could not be reliably inflated to a base-year. Therefore the then-year data were used, which overestimates the cost growth slightly.				

Bibliography

[1] G. Colvin, "Adm. Mike Mullen: Debt is still biggest threat to U.S. security," CNN, 10 May 2012. [Online]. Available: http://management.fortune.cnn.com/2012/05/10/admiral-mike-mullen/. [Accessed 24 May 2012].

[2] E. O'Keefe, "Mullen: Despite deal, debt still poses the biggest threat to U.S. national security," The Washington Post, 2 August 2011. [Online]. Available: http://www.washingtonpost.com/blogs/checkpoint-washington/post/mullen-despite-deal-debt-still-a-risk-to-national-security/2011/08/02/gIQAhSr2oI_blog.html. [Accessed 24 May 2012].

[3] J. P. Smirnoff and M. J. Hicks, "The impact of economic factors and acquisition reforms on the cost of defense weapon systems," *Review of Financial Economics,* vol. 17, no. 1, pp. 3-13, 2008.

[4] K. W. Tyson, R. Nelson, N. I. Om and P. R. Palmer, "Acquiring Major Systems: Cost and Schedule Trends and Acquisition Initiative Effectiveness," Institute for Defense Analyses, Alexandria, Va, 1989.

[5] M. Lorell and J. C. Graser, "An Overview of Acquisition Reform cost Savings Estimates," The RAND Corporation, Santa Monica, CA, 2001.

[6] G. Porter, B. Gladstone, C. V. Gordon, N. Karvonides, R. R. Kneece Jr, J. Mandelbaum and W. D. O'Neil, "The Major Causes of Cost Growth in Defense Acquisition," Institute for Defense Analyses, 2009.

[7] B. D. Rostker, R. S. Leonard, O. Younossi and M. V. Arena, "Cost Controls: How Government Can Get More Bang for Its Buck," *RAND Review,* pp. 18-25, 2009.

[8] M. V. Arena, R. S. Leonard, S. E. Murray and O. Younossi, "Historical Cost Growth of Completed Weapon System Programs," The RAND Corporation, Santa Monica, CA, 2006.

[9] M. V. Arena, Y. Obaid, L. A. Galway, B. Fox, J. C. Graser, J. M. Sollinger, F. Wu and W. Carolyn, Impossible Certainty: Cost Risk Analysis for Air Force Systems, Santa Monica, CA: RAND Corporation, 2006.

[10] 111th Congress, *Weapon Systems Acquisition Reform Act of 2009,* Washington DC, 2009.

[11] "U.S. Code, Title 10, Section 2432, Selected Acquisition Reports," 2004.

[12] National Research Council, "Evaluation of U.S. Air Force Preacquisition Technology Development," The National Academies Press, Washington DC, 2011.

[13] J. A. Drezner, J. M. Jarvaise, R. W. Hess, P. G. Hough and D. Norton, "An Analysis of Weapon System Cost Growth," The RAND Corporation, Santa Monica, CA, 1993.

[14] O. Younossi, M. V. Arena, R. S. Leonard, C. R. Roll, A. Jain and J. M. Sollinger, "Is Weapon System Cost Growth Increasing? A Quantitative Assessment of Completed and Ongoing Programs," The RAND Corporation, Santa Monica, CA, 2007.

[15] D. L. McNicol, "Cost Growth in Major Weapon Procurement Programs," Institute for Defense Analyses, Alexandria, VA, 2004.

[16] I. Blickstein, M. Boito, J. A. Drezner, J. Dryden, K. Horn, J. G. Kallimani, M. C. Libicki, M. McKernan, R. C. Molander, C. Nemfakos, C. J. R. Ohlandt, C. Reilly, R. Rudavsky, J. M. Sollinger, K. W. Webb and C. Wong, "Root Cause Analyses of Nunn-McCurdy Breaches: Vol 1: Zumwalt-Class Destroyer, Joint Strike Fighter, Longbow Apache, and Wideband Global Satellite," The RAND Corporation, Santa Monica, CA, 2011.

[17] M. F. Cancian, "Cost Growth: Perception and Reality," Defense Acquisition University, 2010.

[18] J. G. Bolton, R. S. Leonard, M. V. Arena, O. Younossi and J. M. Sollinger, "Sources of Weapon System Cost Growth: Analysis of 35 Major Defense Acquisition Programs," The RAND Corporation, Santa Monica, CA, 2008.

[19] W. D. O'Neil, "Cost Growth in Major Defense Acquisition: Is There a Problem? Is There a Solution?," Defense Acquisition University, 2011.

[20] M. V. Arena, O. Younossi, K. Brancato, I. Blickstein and C. A. Grammich, "Why Has the Cost of Fixed-Wing Aircraft Risen?," The RAND Corporation, Santa Monica, CA, 2008.

[21] GAO, "Best Practices: An Integrated Portfolio Management Approach to Weapon System Investments Could Improve DOD's Acquisition Outcomes," Washington DC, 2007.

[22] GAO, "Defense Acquisitions: Observations on Weapon Program Performance and Acquisition Reforms," GAO, Washington D.C., 2010.

[23] GAO, "Defense Acquisitions: Strong Leadership is Key to Planning and Executing Stable Weapon Programs," GAO, Washington D.C., 2010.

[24] G. Hagan, Glossary of Defense Acquisition Acronyms & Terms, Fort Belvoir, VA: Defense Acquisition University Press, 2011.

[25] K. W. Tyson, R. J. Nelson, C. D. Gogerty, B. R. Harmon and A. W. Salerno, "Prototyping Defense Systems," Institute for Defense Analyses, 1991.

[26] M. J. Sullivan, "Defense Acquisitions: Strong Leadership is Key to Planning and Executing Stable Weapon Programs," GAO, Washington D.C., 2010.

[27] USD(AT&L), *Department of Defense Instruction 5000.02,* 2008.

[28] K. W. Tyson, R. J. Nelson, C. D. Gogerty, B. R. Harmon and A. W. Salerno, "Prototyping Defense Systems," IDA, 1991.

[29] G. K. Smith, A. A. Barbour, T. L. McNaugher, M. D. Rich and W. L. Stanley, "The Use of Prototypes in Weapon System Development," RAND, 1981.

[30] J. A. Drezner, "The Nature and Role of Prototyping in Weapon System Development," RAND Corporation, Santa Monica, CA, 1992.

[31] D. C. Aronstein and A. C. Piccirillo, HAVE BLUE and the F-117A: Evolution of the "Stealth Fighter", Reston, VA: American Institute of Aeronautics and Astronautics, Inc., 1997.

[32] B. Norton, STOL Progenitors: The Technology Path to a Large STOL Aircraft and the C-17A, Reston, VA: American Institute for Aeronautics and Astronautics, Inc., 2002.

[33] T. H. McMullen, "Opening Remarks," *AIAA Aircraft Prototype and Technology Demonstrator Symposium,* pp. XI-XIV, 1983.

[34] Naval Center for Cost Analysis, *Joint Inflation Calculator,* 2010.

[35] SAF/FMCEE, *Inflation Calculator,* 2012.

[36] P. G. Hough, "Pitfalls in Calculating Cost Growth from Selected Acquisition Reports," The RAND Corporation, Santa Monica, CA, 1992.

[37] E. Dews, G. K. Smith, A. Barbour, E. Harris and M. Hesse, "Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s," The RAND Corporation, Santa Monica, CA, 1979.

[38] J. S. Milton and J. C. Arnold, Introduction to Probability & Statistics, 4th Revised ed., New York, NY: Mcgraw Hill Higher Education, 2002.

[39] G. a. B. R. L. Casella, Statistical Inference, 2nd ed., Duxbury Press, 2001, p. 625.

[40] D. R. Jacques and D. D. Strouble, "A-10 Thunderbolt II (Warthog) Systems Engineering Case Study," Air Force Center for Systems Engineering, Wright-Patterson AFB, OH.

[41] D. C. Aronstein and A. C. Piccirillo, "The Lightweight Fighter: A Successful Approach to Fighter Technology Transisiton," AIAA, Arlington, VA, 1996.

[42] D. C. Aronstein, M. J. Hirschberg and A. C. Piccirillo, Advanced Tactical Fighter To F-22 Raptor, Reston, Virgina: American Institute of Aeronautics and Astronautics, 1998.

[43] GAO, "Military Airlift: Cost and Complexity of the C-17 Aircraft Research and Development Program," Washington DC, Mar 1991.

[44] R. J. LoCastro, "Analysis of the C-17 Acquisition: Did the Air Force Get Their Money's Worth?," Air Command and Staff College, Maxwell AFB, AL, 2000.

[45] S. A. Arnold, J. S. Byun, H. A. Cloud, A. O. Gallo, M. W. Gonwa, B. R. Harmon, P. R. Patel, C. D. Sullivan, J. R. Hiller and P. F. Bronson, "WSARA 2009: Joint Strike Fighter Root Cause Analysis," Institute for Defense Analyses, Alexandria, VA, 2010.

[46] M. D. Maisel, D. J. Giulianetti and D. C. Dugan, "The History of the XV-15 Tilt Rotor Research Aircraft: From Concept to Flight," NASA, 2000.

[47] M. D. Marks, "Prototyping For Fun and Profit," *AIAA Aircraft Prototype and Technology Symposium*, pp. 1-7, 1983.

[48] F. E. Armstrong, "From New Technology Development to Operational Usefullness," *AIAA Aircraft Prototype and Technology Symposium*, pp. 9-17, 1983.

[49] K. V. Stenberg, "YAV-8B Flight Demonstration Program," *AIAA Aircraft Prototype and Technology Symposium*, pp. 103-112, 1983.

[50] H. J. Hillaker, "The F-16 Technology Demonstrator, A Prototype, and A Flight Demonstrator," *AIAA Aircraft Prototype and Technology Symposium*, pp. 113-126, 1983.

[51] J. E. Steiner and L. K. Montle, "Large Jet Aircraft Validation and Demonstrations: An Overview of Boeing Experience," *AIAA Aircraft Prototype and Technology Symposium*, pp. 147-166, 1983.

[52] P. E. Davies and A. M. Thornborough, The Harrier Story, Annapolis, MD: Naval Institute Press, 1996.

[53] B. Kinzig, "Global Hawk Systems Engineering Case Study," Air Force Center for Systems Engineering, Wright Patterson AFB, OH.

[54] Unknown, "The Aircraft Sufficiency Review Handbook," RAND, 2011.

[55] M. Lush, *Implementation of Weapon Systems Acquisition Reform Act (WSARA) of 2009*, OUSD/AT&L, 2009.

[56] B. Fox, M. Boito, J. C. Graser and O. Younossi, "Test and Evaluation Trends and Costs for Aircraft and Guided Weapons," The RAND Corporation, Santa Monica, CA, 2004.

[57] J. N. Fox, P. M. Kodzwa, D. M. Tate and F. B. Patricia, "Global Hawk: Root Cause Analysis of Projected Unit Cost Growth," Institute for Defense Analyses, Alexandria, VA, 2011.

[58] R. S. Leonard and J. A. Drezner, "Innovative Development: Global Hawk and Dark Star - HAE UAV ACTD Program Description and Comparative Analysis," The RAND Corporation, Santa Monica, CA, 2002.

[59] E. C. Mishler, "The A-X Specialized Close Air Support Aircraft: Origins and Concept Phase, 1961-1970," Office of History, Headquarters Air Force Systems Command, 1977.

[60] G. M. Watson, "The A-10 Close Air Support Aircraft: From Development to Production 1970-1976," Office of History, Headquarters Air Force Systems Command.

[61] Predator System Program Office, *Predator Single Acquisition Management Plan (SAMP),* Wright-Patterson AFB, OH, 1997.

[62] *Extracts from U.S. Accounting Office Staff Study Lightweight Fighter Prototype Program and the Air Combat Fighter Program.*

[63] J. P. Jacobs, "Test Pilots' Perspective of Prototype Flying," *AIAA Aircraft Prototype and Tecnology Symposium,* pp. 39-42, 1983.

[64] M. R. Thirtle, R. V. Johnson and J. L. Birkler, "The Predator ACTD: A Case Study for Transition Planning to the Formal Acquisition Process," The RAND Corporation, Santa Monica, CA, 1997.

[65] E. Hehs and J. Rhodes, "F-22 Milestones - Part 1," *Code One Magazine,* vol. 27, no. 1, pp. 30-35, 2012.

[66] E. Hehs, "F-22 Design Evolution, Part I," *Code One Magazine,* vol. 13, no. 2, 1998.

[67] E. Hehs, "F-22 Design Evolution, Part II," *Code One Magazine,* vol. 13, no. 4, 1998.

[68] F-16 System Program Office, *F-16 Decision Coordinating Paper,* Wright-Patterson AFB, OH, 1977.

[69] A-10 System Program Office, *A-10 Specialized Close Air Support Aircraft Official Program Office Estimate,* Wright-Patterson AFB, OH, 1973.

[70] C-X System Program Office, *C-1XA For Comment Draft Decision Coordinating Paper Milestone II,* Wright-Patterson AFB, OH, 1977.

[71] AMST System Program Office, *AMST Prototype Program Command Assessment Review*, Wright-Patterson AFB, OH, 1976.

[72] Tecolote Research, Inc. , "AFCAA Milestone A Cost Data Collection and Methods Improvement: Advanced Tactical Fighter (F-22)," 2011.

[73] Tecolote Research, Inc. , "AFCAA Milestone A Cost Data Collection and Methods Improvement: Joint Strike Fighter-F-35," 2011.

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 074-0188*

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of the collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
14 Jun 2012	Group Research Project	3 Feb 2012 – 14 Jun 2012

4. TITLE AND SUBTITLE	
A Quantitative Analysis of the Benefits of Prototyping Fixed-Wing Aircraft	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	**5d. PROJECT NUMBER** 12V118
Walter B. Harvey, Major, USAF and Charles M. Ryan, Major, USAF	**5e. TASK NUMBER**
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/ENV) 2950 Hobson Way, Building 640 WPAFB OH 45433-8865	AFIT/GSE/ENV/12-J
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)** HVA
Sponsor Agency Name, if none, type "Intentionally Left Blank" Ms. Donna Milam, ASC/XR Bldg 11 Wright-Patterson AFB OH 45433 (937) 255-8586	**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Prototyping received renewed emphasis in the Weapon Systems Acquisition Reform Act (WSARA) of 2009 and the revision to DoDI 5000.02 that preceded it. One of the intentions of WSARA is to reduce cost growth among acquisition programs. The purpose of this research was to determine if cost growth is reduced for fixed-wing aircraft acquisition programs that used early prototyping (prior to MS B). The research also sought to identify trends between cost growth and schedule or prototyping cost. The research showed no discernible trends. While the research did not reveal a statistically significant reduction in normalized average total acquisition program cost growth, it does offer insight into the need to further clarify acquisition policy guidance.

15. SUBJECT TERMS
Prototype, Systems Engineering, Cost Growth, Fixed-Wing Aircraft

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					Research Advisor, Dr. John Colombi
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(Include area code)*
U	U	U	UU or SAR	56	(937) 255-3636, x x334 (john.colombi@afit.edu)

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18